

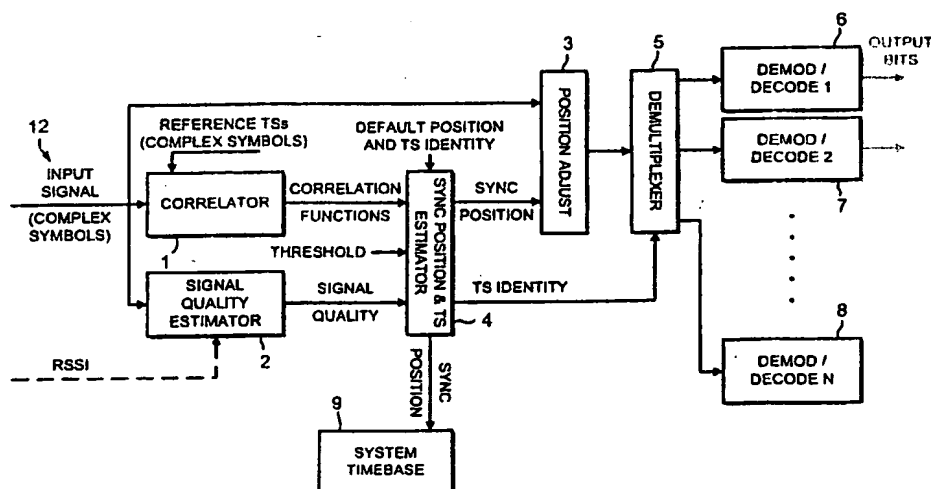


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<b>(21) International Application Number:</b> PCT/GB99/04297 <b>(22) International Filing Date:</b> 17 December 1999 (17.12.99) <b>(30) Priority Data:</b> 9902755.9                      8 February 1999 (08.02.99)                      GB <b>(71) Applicant (for all designated States except US):</b> SIMOCO INTERNATIONAL LIMITED [GB/GB]; St. Andrews Road, P.O. Box 24, Cambridge CB4 1DP (GB). <b>(72) Inventors; and</b> <b>(75) Inventors/Applicants (for US only):</b> STEPHENS, Peter, William [GB/GB]; 10 St. Catherines, Ely, Cambridge CB6 1AP (GB). McMAHON, Paul [GB/GB]; 91 Cambridge Road, Hardwick, Cambridge CB3 7QQ (GB). <b>(74) Agent:</b> FRANK B. DEHN & CO.; 179 Queen Victoria Street, London EC4V 4EL (GB).		<b>(81) Designated States:</b> AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW). Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM). European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report.</i>

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(54) Title: DIGITAL SIGNAL RECEIVER SYNCHRONISATION



## (57) Abstract

A digital radio receiver receives and captures an input digital signal (12) which may, for example, be in the form of complex numbers representing symbols of the received signal at baseband. This received signal is fed into a correlator (1), signal quality estimator (2) and a position adjuster (3). The correlator (1) correlates a selected portion of the received symbols with a set of reference symbol sequences and produces a correlation parameter as a function of delay over a finite window of time for each reference symbol sequence. In addition to the above correlation parameter determination, the signal quality estimator (2) analyses the received signal and produces a signal quality estimate for each set of correlation parameters. The estimated signal quality is passed to the synchronisation position and training sequence estimator (4) along with the set of correlation parameters from the correlator (1). The synchronisation position and training sequence estimator (4) uses the signal quality estimate and correlation parameters to compute a decision function which is used to select the optimum synchronisation position and training sequence identity for the selected portion of input signal received.

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Digital Signal Receiver Synchronisation

5           The present invention relates to a method of and an apparatus for synchronising a receiver to a digital signal.

10           In digital communications systems information is transmitted as a stream or sequence e.g. of symbols, bits or similar. The digital signal transmission may, for example, be optical, electrical, acoustic or via radio waves. To be able to correctly decode the information contained in the received signal, the receiver must be able to identify accurately the  
15           positions of the symbols, bits or similar in the input signal stream and synchronise its various signal processing functions to the input signal stream so that the functions are performed correctly on the symbols, bits or similar in the stream. In other words, the  
20           receiver must synchronise to the received digital signal in order to correctly decode the information contained in the signal.

          For example, in digital radio communications systems (such as the TETRA (TERrestrial TRunked RADio) system) information is transmitted as a stream or  
25           sequence, e.g. of symbols, or bits, or similar, which are used to modulate a radio frequency carrier wave. In the receiver the received signal is frequency downconverted to baseband and if appropriate further  
30           demodulated to provide a stream of symbols, bits or similar. The radio receiver must synchronise to the received digital radio signal to be able to decode correctly the information contained in that signal.

          Such synchronisation is often assisted by including  
35           in the transmitted signal (e.g. radio wave) predefined structures or signal portions which the receiver can recognise and use to synchronise to the signal. In the

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TETRA system the predefined signal structures are called training sequences.

In many systems, including TETRA, predefined signal structures or training sequences can also be used for purposes other than synchronisation, such as the training of an adaptive digital equaliser, or to indicate the type of encoding applied to the information by the transmitter. In such a system which makes use of several training sequences, the receiver must also be able to identify which of the several possible training sequences has been transmitted in the signal so that it can take the appropriate action.

In practice in a digital radio communications system (and other digital signalling systems) the signal received by a receiver can be corrupted e.g. by noise, and also distorted, e.g. due to the propagation channel, from its original form. This makes it more difficult to identify the correct synchronisation point (i.e. symbol or bit positions) and the correct training sequence in the transmitted signal. Any mistake by the receiver in estimating the correct synchronisation point, or in the identification of the training sequence, leads to errors in the decoding of the received signal, and an increase in the bit error rate in the decoded received signal.

To assist in synchronisation point and training sequence identification, in a digital radio system the receiver will normally record or capture a portion or time window of the transmitted signal which it expects to contain the transmitted training sequence (the receiver will have previously, as is known in the art, identified the approximate location of the training sequence using known techniques) and then compare it with one or more reference training sequences, at one or more different time positions in the window, to try to establish the best match (which would then be selected as the transmitted training sequence and synchronisation point (i.e. symbol, etc positions)).

This comparison is typically done as a correlation check, as is known in the art, in which the selected received signal portion is correlated with a set of reference training sequences. The correlation of each reference training sequence for each of a set of  
5 predetermined time delays from the start of the recorded time window is assessed. The time delays effectively move the symbols or bits in the reference training sequence to different positions in the time window. This allows an assessment of where exactly the symbols  
10 or bits of the received training sequence are in the time window (this is necessary because the receiver is not sure exactly when in the time window the transmitted training sequence starts). The time delay with the best  
15 correlation is effectively the best overlap or match with the received signal, and thus indicates the position of the training sequence in the signal and thus the synchronisation point for the receiver.

It is an object of the present invention to provide  
20 an improved method of and apparatus for estimating the synchronisation position.

According to a first aspect of the present invention, there is provided a method of estimating the synchronisation position of a received digital signal,  
25 comprising:

comparing a selected portion of the received signal with one or more reference predetermined signal sequences;

estimating the quality of the received signal; and  
30 estimating the synchronisation position on the basis of the comparison and the estimated signal quality.

According to a second aspect of the present invention, there is provided an apparatus for estimating  
35 the synchronisation position of a received digital signal, comprising:

means for comparing a selected portion of the

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received signal with one or more reference predetermined signal sequences;

means for estimating the quality of the received signal; and

5 means for estimating the synchronisation position on the basis of the comparison and the estimated signal quality.

In these aspects of the present invention, the synchronisation position of a received digital signal is  
10 estimated on the basis of both a comparison of the signal with predetermined reference signal sequences (e.g. training sequences) and the estimated quality of the received signal.

The Applicants have found that signal quality can  
15 affect and distort correlation estimates for a received digital radio signal. For example in a fading radio channel a strong signal which in reality has a very poor correlation may still give a good or high correlation result using known correlation measures, thereby  
20 erroneously indicating good correlation. Conversely, a weak signal but with no fading will tend to give a low correlation result with known correlation measures, even though in reality the correlation may be good. These spurious correlation results can lead to erroneous and  
25 unreliable synchronisation decisions.

However, the Applicants have found that by including signal quality estimates in the synchronisation process, such spurious correlation results can be taken account of and their effect (e.g.  
30 the possibility of them introducing errors into the synchronisation process) reduced. For example, the signal quality estimate can be used to facilitate the rejection from the synchronisation decision process of spurious good correlation results caused by a strong  
35 signal which in reality has a poor correlation. It can also be used to ensure the consideration in the synchronisation process of an (abnormally) low

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correlation result from a weak signal (which can in fact be reliably used in the synchronisation process) which would in prior art correlation techniques have been rejected.

5        Thus by using both a signal quality estimate and the known reference signal sequence comparison, the reliability of synchronisation position estimation for a digital signal and in particular for a digital radio signal in a digital radio communications receiver can be improved.

10        The Applicants have also found that, for the same reasons, using a signal quality estimate as well as reference signal sequence comparisons provides a more reliable method of identifying which of a plurality of predetermined signal sequences (e.g. training sequences) has been received.

15        Thus, according to a third aspect of the present invention there is provided a method of identifying which of a plurality of predetermined signal sequences is present in a received digital signal, comprising:  
20        comparing a selected portion of the received signal with two or more reference predetermined signal sequences;

25        estimating the quality of the received signal; and selecting the identity of a predetermined signal sequence in the received signal on the basis of the comparison and the estimated signal quality.

30        According to a fourth aspect of the present invention, there is provided an apparatus for identifying which of a plurality of predetermined signal sequences is present in a received digital signal, comprising:

35        means for comparing a selected portion of the received signal with two or more reference predetermined signal sequences;

      means for estimating the quality of the received signal; and

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means for selecting the identity of a predetermined signal sequence in the received signal on the basis of the comparison and the estimated signal quality.

5 In a particularly preferred embodiment, where appropriate, the invention comprises estimating the synchronisation position and identifying the signal (training) sequence using the comparison of the received signal with two or more predetermined reference signal sequences and the estimated received signal quality.

10 The present invention thus provides a method and apparatus which can make better decisions about the synchronisation position of and/or training sequence identity in a received digital signal. The invention is applicable to digital signals in any form, such as  
15 optical, electrical or acoustic digital signals. It is particularly suitable for use with digital radio systems (in which the received signal will be a radio signal which includes digitally encoded information) and in particular to TDMA (Time Division Multiple Access)  
20 digital systems such as TETRA in which training sequences are employed to facilitate synchronisation and to convey information. The invention results in a reduced bit error rate in the decoded received signal. It accordingly provides a digital (radio) receiver which  
25 is more robust in operation and less effected by, *inter alia*, fades. It also permits simpler and less expensive hardware to be used in the receiver.

The comparison of the received signal with the reference signal sequence or sequences should compare  
30 the sequence of symbols, or bits, etc. in the selected portion of the received signal with the predetermined sequence of symbols, or bits, etc. respectively representing the reference sequence or sequences to assess how well they match or correlate. In a  
35 particularly preferred embodiment the selected portion of the received signal with which the comparison is made is a portion or time window of the received signal where

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it is expected that the predetermined signal or training sequence should be present. (This is possible because signal protocols normally denote predetermined locations for transmitting training sequences, etc. There are also, as is known in the art, techniques for identifying approximately the position of a training sequence in a given digital signal.)

Where the synchronisation position is being sought, the comparison is preferably made by comparing the or each reference sequence with the received signal portion at each of a plurality of predetermined different time delays relative to the start of the selected received signal portion (e.g. the selected predetermined time window of the signal) with which it or they are being compared. The time delay for the best match then gives an indication, as is known in the art, of the actual position of the symbols or bits in the received signal portion, i.e. the synchronisation position. The set of predetermined time delays should be selected appropriately, e.g. on the basis of the possible symbol positions or spacings in the received signal.

Where the identification of the signal sequence (i.e. training sequence) in the received signal is sought, the comparison should be made with each of a set of predetermined reference sequences, preferably for a set of predetermined time delays for each predetermined reference sequence. The best match then gives, as is known in the art, an indication of the identity of the transmitted signal sequence.

In a particularly preferred embodiment the comparison comprises assessing the correlation of the received signal portion with a set of one or more reference signal sequences, most preferably as a function of a set of two or more predetermined time delays over the window of time of the selected portion of the received signal, for each of the reference signal sequences. This correlation can, for example, comprise

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a correlation function of the form:

$$C_R(\tau) = \left( \sum_{t=-T/2}^{T/2} y(t-\tau) S_R^*(t) \right)$$

where  $C_R(\tau)$  is the estimated correlation parameter for  
5 the reference signal sequence,  $R$ , for a predetermined  
time delay,  $\tau$ . In the above equation,  $y$  is the input  
signal  $I + jQ$  where  $I$  is the real part and  $Q$  is the  
imaginary part of the received signal at baseband,  $S_R$  is  
the reference signal sequence  $I + jQ$  where  $I$  is the real  
10 part and  $Q$  is the imaginary part of the reference signal  
at baseband,  $T$  is the time window (i.e. the selected  
received signal portion) over which the correlation is  
estimated, and  $*$  denotes the complex conjugate. Under  
ideal, steady-state conditions the higher the value of  
15 the correlation parameter the better the match with the  
identity of the reference sequence and the  
synchronisation position represented by the time delay.  
However, as noted above, in a real fading radio channel  
this is not always true, and the present invention helps  
20 to address this.

Thus according to a fifth aspect of the present  
invention, there is provided a method of synchronising a  
radio communications receiver for use in a digital radio  
system to a received digitally encoded signal, wherein  
25 the synchronisation of the receiver to the received  
signal is based on the correlation of a selected portion  
of the received signal with one or more predetermined  
reference signal sequences and the estimated quality of  
the received signal.

30 According to a sixth aspect of the present  
invention, there is provided an apparatus for  
synchronising a digital radio communications receiver to  
a received digitally encoded signal, comprising

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synchronisation means which uses the correlation of a selected portion of the received signal with one or more predetermined reference signal sequences and the estimated quality of the received signal to control the synchronisation of the receiver to the received signal.

The invention also extends accordingly to a method of or apparatus for identifying which of a plurality of predetermined signal sequences is present in a received digital signal which uses the correlation of a selected portion of the received signal with two or more predetermined reference signal sequences and the estimated quality of the received signal to identify the signal sequence.

The quality of the received signal can be estimated as desired. In a digital radio system it could, for example, be derived from the baseband signal, or be supplied from elsewhere in the receiver. It could, for example, be based on the received signal level or received signal strength indication (RSSI in TETRA). Other parameters indicative of signal quality such as the variation of a set of parameters determined for samples of the received signal could also be used.

Two or more parameters indicative of signal quality can be used for the signal quality estimate, if desired. In such an arrangement the parameters used are preferably weighted according to their relative importance.

The signal quality is preferably estimated only for the selected portion (e.g. time window) of the received signal with which the above discussed reference signal sequence comparison is made. This is because in, for example, fading radio channels, poor signal quality is often localised over a relatively short time period (i.e. during a fade), such that in an otherwise adequate signal, the selected signal portion could still be very poorly received. Thus by assessing the signal quality over the signal portion of time period relevant to the

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comparison, a better estimation of the actual signal quality at the relevant time (and thus of the accuracy and reliability of that comparison) is obtained.

5 If desired only the signal quality at the time delay corresponding to the maximum of the correlation function can be estimated and used in the synchronisation position and/or signal sequence identity selection process. This provides a less complex but potentially less reliable arrangement.

10 In a particularly preferred embodiment the signal quality estimate is an estimate of the received signal power as a function of delay over the correlation window:

$$Q(\tau) = \left( \sum_{t=-T/2}^{T/2} y^2(t-\tau) \right)$$

15 where  $Q(\tau)$  is the signal quality estimate,  $y$  is the received signal  $I + jQ$  where  $I$  is the real part and  $Q$  is the imaginary part of the received signal at baseband at the time  $(t-\tau)$ ,  $\tau$  is the predetermined time delay and  $T$  is the time window over which the correlation is  
20 estimated.

The results of the signal comparison and signal quality estimate should be used to select the synchronisation position and/or signal (training) sequence identity appropriately in accordance with how  
25 those parameters are determined (e.g. to ensure that potentially spuriously high correlation results are rejected but spuriously low correlation results are included in the selection process).

Most preferably the signal comparison results and  
30 signal quality estimates are used to define a decision function on which synchronisation position and training sequence identity selection can be based, e.g. by taking the time delay and/or reference training sequence

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identity corresponding to the maximum of the decision function.

5 The decision function preferably comprises either the product of the correlation value determined from the signal comparison and the corresponding signal quality estimate value (e.g. signal quality estimate discussed above for the corresponding reference signal sequence and predetermined time delay) or the ratio of these values. Thus, the maximum ratio or product with respect to time delay and/or reference signal sequence can be used to identify the appropriate synchronisation position and/or signal sequence for the received signal.

10 The product of the values should be used where a signal giving a lower signal quality estimate tends to result in a spuriously high correlation value (such that the overall decision function value will tend to be lower in spite of the spuriously high correlation value). Conversely, the correlation value divided by the signal quality estimate value should be used where a signal giving a higher signal quality estimate tends to result in a spuriously high correlation value (such that the overall decision function value will tend to be lower in spite of the spuriously high correlation value).

25 Preferably the decision function is such that it always produces values falling in a fixed range (e.g. between 0 and 1) regardless of the actual signal quality estimated and signal comparison result, and most preferably also irrespective of the actual signal level. This makes comparison between decision values derived for different physical conditions more straightforward and permits, for example, the setting of a single threshold to reject spurious decision values for e.g. all signal levels and/or other physical conditions. A scaling factor may be included in the decision function to achieve this, if desired.

35 In a particularly preferred embodiment the decision

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function comprises dividing a value representative of the correlation of the selected portion of the received signal with a reference predetermined signal sequence by a value representing the power of the received signal (preferably the power as measured over the selected signal portion).

This decision function has been found to be particularly reliable. It will tend to eliminate from the synchronisation process strong signals in which a fade has hit the training sequence, because although such signals will give spuriously high correlation values, they will also give very high signal power values and thus the resulting decision function values will be relatively low, such that such signals will not determine the synchronisation process. On the other hand, for weak signals with no fading (whose correlation is therefore good, but which in practice produce low correlation values), the decision function will be relatively high (since although the correlation value is abnormally low, the weak signal gives a lower value of signal power, therefore giving an increased decision function value). Thus these signals which would be rejected erroneously in known correlation processes can be determinative in the synchronisation process. In effect the decision function mitigates the spurious increase in the correlation function that may occur for higher power signals and mitigates the spurious decrease in the correlation function that may occur for lower power signals.

Thus, according to a seventh aspect of the present invention, there is provided a method of estimating the synchronisation position of a received digital signal or of identifying which of a plurality of predetermined signal sequences is present in a received digital signal, comprising:

estimating a correlation value or values representative of the correlation of a selected portion

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of the received signal with one or more reference predetermined signal sequences;

estimating the received signal power; and

5 estimating the synchronisation position or signal sequence identity using the estimated correlation value divided by the signal power estimate.

According to a eighth aspect of the present invention, there is provided an apparatus for estimating the synchronisation position of a received digital  
10 signal or for identifying which of a plurality of predetermined signal sequences is present in a received digital signal, comprising:

means for estimating a correlation value or values representative of the correlation of a selected portion  
15 of the received signal with one or more reference predetermined signal sequences;

means for estimating the received signal power; and

means for estimating the synchronisation position or signal sequence identity using the estimated  
20 correlation value divided by the signal power estimate.

In this embodiment and these aspects of the invention, the signal sequence identity and synchronisation position are preferably selected by considering the values of the decision function (e.g. correlation estimate divided by signal power estimate)  
25 for plural time delays and reference signal sequences, e.g. to find which time delay and reference signal sequence combination gives the maximum value of the decision function.

30 In a particularly preferred embodiment, a decision function at delay  $\tau$  for training sequence R is defined as:

$$Y_R(\tau) = \frac{C_R(\tau)}{Q(\tau) \left( \sum_{t=-T/2}^{T/2} S^2(t) \right)}$$

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$\sum_{t=-T/2}^{T/2} S^2(t)$  is a scaling factor as discussed above which ensures that the values of the decision function always lie in the range of 0 to 1.

In this embodiment, the signal sequence identity and synchronisation position is preferably selected by searching over the set of time delays  $\tau$  and reference signal sequences  $R$  to find which time delay and reference signal sequence combination gives the maximum value of the decision function.

In a particularly preferred embodiment, comparison results, signal quality estimates, and/or the determined decision functions are only used in the synchronisation position estimation or signal sequence identification, if they exceed a predetermined threshold. This effectively rejects particularly bad or unreliable results from the process. If all results are rejected, a default synchronisation position may be used, and a default, e.g. the most commonly used, signal sequence identity selected.

The method and apparatus of the present invention can use the received signal in any appropriate form, for example before or after demodulation of the received signal as desired. This will simply affect in exactly what form the sequence of information (i.e. symbols, bits or similar) in the received signal portion and reference signal sequences is.

Although the present invention has been described above with reference to the use of both a comparison of a selected portion of the received signal with one or more reference predetermined signal sequences and the estimated quality of the received signal to estimate the synchronisation position of and/or identify a signal sequence in, a received digital signal, it is believed that using the estimated signal quality for the synchronisation or signal sequence identification

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process in itself is advantageous.

Thus, according to a ninth aspect of the present invention, there is provided a method of estimating the synchronisation position of a received digital signal, or of identifying which of a plurality of predetermined signals sequences is present in the received digital signal, comprising:

estimating the quality of the received signal; and using the estimated signal quality in the synchronisation position estimation process or the signal sequence identification process.

According to a tenth aspect of the present invention, there is provided an apparatus for estimating the synchronisation position of a received digital signal, or for identifying which of a plurality of predetermined signal sequences is present in the received digital signal, comprising:

means for estimating the quality of the received signal; and

means for estimating the synchronisation position using the estimated signal quality or for identifying the signal sequence using the estimated signal quality.

The methods in accordance with the present invention may be implemented at least partially using software e.g. computer programs. It will thus be seen that when viewed from further aspects the present invention provides computer software specifically adapted to carry out the methods hereinabove described when installed on data processing means, and a computer program element comprising computer software code portions for performing the methods hereinabove described when the program element is run on a computer. The invention also extends to a computer software carrier comprising such software which when used to operate a signal receiver comprising a digital computer causes in conjunction with said computer said receiver to carry out the steps of the method of the present

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invention. Such a computer software carrier could be a physical storage medium such as a ROM chip, CD ROM or disk, or could be a signal such as an electronic signal over wires, an optical signal or a radio signal such as to a satellite or the like.

It will further be appreciated that not all steps of the method of the invention need be carried out by computer software and thus from a further broad aspect the present invention provides computer software and such software installed on a computer software carrier for carrying out at least one of the steps of the methods set out hereinabove.

A number of preferred embodiments of the present invention will now be described by way of example of only and with reference to the accompanying drawings, in which:

Figure 1 shows schematically part of a digital radio receiver in accordance with the present invention;

Figure 2 shows schematically part of a digital radio receiver in accordance with the present invention; and

Figures 3 and 4 are graphs showing decision function values derived in accordance with the present invention against time delay.

Figure 1 shows schematically part of a digital radio receiver. The receiver receives and captures an input digitally encoded signal 12 which may, for example, be in the form of complex numbers representing symbols of the received signal at baseband. This received signal is fed into a correlator 1, signal quality estimator 2 and a position adjuster 3.

The correlator 1 correlates a selected portion of the received symbols with a set of reference training sequences and produces a correlation parameter as a function of delay over a finite window of time for each reference training sequence. In effect, the correlator compares a selected or particular portion or time window

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of the received input signal where it expects the training sequence to have been placed in the input signal by the transmitter (the receiver can also initially identify the approximate location of the training sequence using known techniques for so doing) with each of a set reference training sequences, with the comparison with each respective reference training sequence also being carried out over a set of predetermined time delays relative to the start of the time window selected. The set of time delays are predetermined and effectively step or index the reference training sequence along the selected time window of the input signal so as to effectively compare the symbols or bits reference training sequence with different positions in the input signal in the predetermined time window.

The correlation parameter,  $C_R(\tau)$ , for the reference training sequence,  $R$ , at the time delay,  $\tau$ , is defined as:

$$C_R(\tau) = \left( \sum_{t=-T/2}^{T/2} y(t-\tau) S_R^*(t) \right)$$

where  $y$  is the input signal,  $S_R$  is the reference training sequence,  $T$  is the time window over which the correlation is estimated, and  $*$  denotes the complex conjugate.

In addition to the above correlation parameter determination, the signal quality estimator 2 analyses the received signal and produces a signal quality estimate for each set of correlation parameters. The signal quality estimate may be derived from the baseband

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signal, or may be supplied from elsewhere in the receiver. It may for example comprise the received signal strength indication (RSSI) in the TETRA system. If desired, both the baseband signal quality estimate and the received signal strength indication can be used to produce an overall signal quality estimate. In this case, if a number,  $N$ , of different signal quality estimates are used, the overall signal quality estimate,  $\bar{Q}(\tau)$  to be used may be derived as follows:

$$\bar{Q}(\tau) = \frac{\sum_{q=1}^N W_q Q_q}{\sum_{q=1}^N W_q}$$

where each of the quality estimates  $Q_q$  is weighted according to its importance by a weighting factor  $W_q$ .

In the present embodiment, the signal quality estimate used,  $Q(\tau)$ , is an estimate of the received signal power as a function of delay,  $\tau$ , over the time window over which the correlation is estimated:

$$Q(\tau) = \sum_{t=-T/2}^{T/2} y^2(t-\tau)$$

In this arrangement the signal quality estimate is derived over the correlation window. This can be important because in fading channels, poor signal quality is often localised over a relatively short interval of time (i.e. during a fade).

The estimated signal quality is passed to the synchronisation position and training sequence estimator 4 along with the set of correlation parameters from the correlator 1.

The synchronisation position and training sequence estimator 4 uses the signal quality estimate and correlation parameters to compute a decision function,

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$\gamma$ , which is used to select the optimum synchronisation position and training sequence identity for the selected portion of input signal received.

5 In the present embodiment, the synchronisation position and training sequence estimator 4 computes a decision function,  $\gamma_R(\tau)$ , for each respective reference training sequence R and predetermined time delay  $\tau$  using the ratio of the appropriate correlation parameter and signal quality estimate:

$$\gamma_R(\tau) = \frac{C_R(\tau)}{Q(\tau) \sum_{t=-T/2}^{T/2} S^2(t)}$$

10 The parameter:

$$\sum_{t=-T/2}^{T/2} S^2(t)$$

is a scaling factor, to ensure that all the decision values lies between 0 and 1.

The training sequence identity and synchronisation position is found by searching the set of decision values  $\gamma_R(\tau)$  over delay  $\tau$  and reference training  
15 sequence R for the maximum decision value:

$$[\text{Training sequence, delay (i.e. synchronisation position)}] = \text{MAX } [\gamma_R(\tau)]_{R,\tau}$$

20

To improve the performance of the system, a threshold can be used to reject decision function estimates which are deemed to be bad or unreliable such that only estimates which meet the threshold are used.  
25 If all the estimates are rejected, a default synchronisation position may be used, and a default training sequence identity selected (e.g. the most commonly used training sequence). In the present

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embodiment a rejection threshold of 0.5 for the decision values could be used (i.e. all decision values below 0.5 rejected).

5        Figures 3 and 4 are graphs of the decision value as a function of delay for one training sequence. Figure 3 shows at delay 2 a good decision value, i.e. indicating the synchronisation position and training sequence identity to use. Figure 4 shows a bad set of decision values. In Figure 4, a fade, for example, has affected  
10       the portion of the received signal containing the training sequence, such that the decision values are low at all time delays. A threshold of 0.5 could be used to prevent the data from Figure 4 being used in the synchronisation position and training sequence identity  
15       selection process.

      The synchronisation position and training sequence estimator 4 selects the synchronisation sequence and training sequence identity appropriately on the basis of the decision values that it determines. The selected  
20       synchronisation position is provided to the position adjustor 3 which advances or retards the input signal by the required amount, as is known in the art. The training sequence identity and position adjusted input  
25       signal are sent to the demultiplexer 5 which routes the signal to the appropriate demodulator and decoder 6, 7, 8 for the training sequence identified (each training sequence identity may require a different decoding).

      The selected synchronisation position is also given to the system timebase 9 which can use it, if  
30       appropriate, to make permanent adjustments to the system clock to minimise the delay for accurate synchronisation in subsequent reception.

      Figure 2 shows an alternative embodiment of the present invention in which the input signal is  
35       demodulated before it is input to the correlator 1. It should be noted that although the apparatus blocks in Figure 2 are given the same reference numerals as the

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corresponding blocks in Figure 1, because they perform effectively equivalent functions, as the skilled person will appreciate, the blocks in Figure 2 are not always absolutely identical in function to the corresponding blocks in Figure 1, because their input signals are different to the input signals to the corresponding block in Figure 1.

In this case the input signal comprises, in, for example, the TETRA system, soft or hard decision values. The arrangement then proceeds as before with correlation parameters estimated as follows:

$$C_R(\tau) = \sum_{t=-T/2}^{T/2} b(t-\tau) S_R(t)$$

Where b is the soft or hard decision signal from the demodulator, and S is the reference training sequence in bits (which therefore takes values of -1 or 1 only). It can be seen that in this arrangement the correlation requires only sum and difference operations, rather than multiply accumulate operations.

The signal quality is then estimated as a function of the soft or hard decision values, rather than the signal power:

$$Q(\tau) = \sum_{t=-T/2}^{T/2} |b(t-\tau)|$$

The decision function can then be determined as:

$$Y_R(\tau) = \frac{C_R(\tau)}{Q(\tau)}$$

(which lies in the range of -1 to +1).

The training sequence identity and appropriate delay (which determines the synchronisation position)

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can then be found as discussed in the first embodiment of the invention.

It can be seen from the above that the present invention takes the signal quality into account when  
5 selecting the training sequence identity and synchronisation position (and preferably uses a default position and training sequence identity if appropriate estimates are not possible). This provides improved bit error rate performance in the decoded received signal  
10 over a conventional system. For example, the applicants have found that for a COSSAP radio simulation using a TETRA HT200 channel model (because that model is particularly badly affected by fading), at reference sensitivity in the TETRA system, synchronisation based  
15 on a single training sequence fails approximately 2% of the time. When a synchronisation failure occurs, 50% of the bits in the signal will be in error, i.e. there is an overall bit error rate of 1% due to the synchronisation failure. With the method of the present  
20 invention, the synchronisation failure rate in the simulation falls to .5%, thereby giving an overall bit error rate of .25% due to synchronisation failure.

The present invention is, as described above, particularly applicable for use in digital radio  
25 communications systems where the digital signal will be derived from a radio signal carrying it. However, it can also be used for other forms of digital signal, and signals which carry a digital signal (and from which the digital signal can be derived), such as optical,  
30 electrical or acoustic (e.g. underwater sonar) signals.

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## CLAIMS

1. A method of estimating the synchronisation position of a received digital signal, comprising:
  - 5 comparing a selected portion of the received signal with one or more reference predetermined signal sequences;
  - estimating the quality of the received signal; and
  - estimating the synchronisation position on the
  - 10 basis of the comparison and the estimated signal quality.
2. A method of identifying which of a plurality of predetermined signal sequences is present in a received  
15 digital signal, comprising:
  - comparing a selected portion of the received signal with two or more reference predetermined signal sequences;
  - estimating the quality of the received signal; and
  - 20 selecting the identity of a predetermined signal sequence in the received signal on the basis of the comparison and the estimated signal quality.
3. The method of claim 1 or 2, comprising both  
25 estimating the synchronisation position of, and selecting the identity of a predetermined signal sequence in, the received signal on the basis of the comparison of a selected portion of the received signal with two or more predetermined reference signal  
30 sequences, and the estimated quality of the received signal.
4. The method of any one of the preceding claims, wherein the received digital signal is derived from a  
35 received radio signal.
5. The method of claim 1, 2, 3, or 4, wherein the

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comparison of the received signal with the reference signal sequence or sequences comprises comparing the selected portion of the received signal with the reference sequence or sequences to assess how well they match or correlate.

6. The method of any one of the preceding claims, wherein the comparison step comprises comparing the or each reference signal sequence with the selected received signal portion at each of a plurality of predetermined different time delays relative to the start of the selected received signal portion.

7. The method of any one of the preceding claims, wherein the comparison step comprises assessing the correlation of the or each reference signal sequence with the selected received signal portion at each of a plurality of predetermined different time delays relative to the start of the selected received signal portion.

8. A method of synchronising a digital radio communications receiver to a received signal, comprising basing the synchronisation of the receiver to the received radio signal on the correlation of a selected portion of the received signal with one or more predetermined reference signal sequences and the estimated quality of the received signal.

9. A method of identifying which of a plurality of predetermined signal sequences is present in a received digital signal, comprising using the correlation of a selected portion of the received signal with two or more predetermined reference signal sequences and the estimated quality of the received signal to identify the signal sequence.

- 25 -

10. The method of any one of the preceding claims, wherein the comparison of the selected received signal portion with the reference signal sequence or sequences is assessed using a correlation function of the form:

5

$$C_R(\tau) = \left( \sum_{t=-T/2}^{T/2} y(t-\tau) S_R^*(t) \right)$$

where:

10  $C_R(\tau)$  is the estimated correlation parameter for the reference signal sequence, R, for a predetermined time delay,  $\tau$ ;  
 $y(t-\tau)$  is the received signal  $I + jQ$  where I is the real part and Q is the imaginary part of the received signal at baseband at the time  $(t-\tau)$ ;  
 $S_R(t)$  is the reference signal sequence  $I + jQ$  where  
 15 I is the real part and Q is the imaginary part of the reference signal at baseband at the time t;  
 T is the time period over which the correlation is estimated; and  
 \* denotes the complex conjugate.

20

11. The method of any one of the preceding claims, wherein the signal quality estimate used is the signal quality estimated for the selected portion of the received signal with which the reference signal sequence  
 25 comparison is made alone.

12. The method of claim 11, wherein the signal quality estimate is an estimate of the received signal power as a function of delay over the correlation window:

30

$$Q(\tau) = \left( \sum_{t=-T/2}^{T/2} y^2(t-\tau) \right)$$

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where:

$Q(\tau)$  is the signal quality estimate for a predetermined time delay  $\tau$ ;

5  $y(t-\tau)$  is the received signal  $I + jQ$  where  $I$  is the real part and  $Q$  is the imaginary part of the received signal at baseband at the time  $(t-\tau)$ ;

$\tau$  is the predetermined time delay; and

$T$  is the time window over which the correlation is estimated.

10

13. The method of any one of the preceding claims, wherein the signal comparison results and signal quality estimates are used to define a decision function on which the synchronisation position estimation and the  
15 signal sequence identity selection are based.

14. The method of claim 13, wherein the decision function includes either the product of the correlation value determined from the signal comparison and the  
20 corresponding signal quality estimate value, or the ratio of those values.

15. The method of claim 13 or 14, wherein the decision function is such that it always produces values falling  
25 within a fixed range regardless of the actual signal quality estimated and the signal comparison result.

16. The method of claim 13, 14 or 15, wherein the decision function includes dividing a value  
30 representative of the correlation of the selected portion of the received signal with a reference predetermined signal sequence by a value representing the power of the received signal.

35 17. A method of estimating the synchronisation position of a received digital signal or of identifying which of a plurality of predetermined signal sequences is present

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in a received digital signal, comprising:

estimating a correlation value or values representative of the correlation of a selected portion of the received signal with one or more reference predetermined signal sequences;

estimating the received signal power; and

estimating the synchronisation position or signal sequence identity using the estimated correlation value divided by the signal power estimate.

18. The method of any one of claims 13, 14, 15 and 16, when dependent upon claims 10 and 12, wherein the decision function  $\gamma_R(\tau)$  at delay  $\tau$  for reference signal sequence R is defined as:

$$\gamma_R(\tau) = \frac{C_R(\tau)}{Q(\tau) \left( \sum_{t=-T/2}^{T/2} S^2(t) \right)}$$

where:

$C_R(\tau)$  is the estimated correlation parameter for the reference signal sequence, R, for a predetermined time delay,  $\tau$ , as defined in claim 10;

$Q(\tau)$  is the signal quality estimate for a predetermined time delay  $\tau$ , as defined in claim 12;

$S(t)$  is the reference signal sequence  $I + jQ$  where I is the real part and Q is the imaginary part of the reference signal at baseband at the time t; and T is the time window over which the correlation is estimated.

19. The method of any one of claims 13, 14, 15, 16 and 18, comprising selecting the signal sequence identity and synchronisation position by searching over the set of time delays and the set of reference signal sequences to find which time delay and reference signal sequence combination gives the maximum value of the decision

function.

20. The method of any one of the preceding claims, wherein the comparison step results, signal quality  
5 estimates, and/or the determined decision functions are only used for the synchronisation position estimation or signal sequence identification, if they exceed a respective predetermined threshold value.

10 21. A method of estimating the synchronisation position of a received digital signal, or of identifying which of a plurality of predetermined signals sequences is present in the received digital signal, comprising:  
estimating the quality of the received signal; and  
15 using the estimated signal quality in the synchronisation position estimation process or the signal sequence identification process.

22. An apparatus for estimating the synchronisation  
20 position of a received digital signal, comprising:  
means for comparing a selected portion of the received signal with one or more reference predetermined signal sequences;  
means for estimating the quality of the received  
25 signal; and  
means for estimating the synchronisation position on the basis of the comparison and the estimated signal quality.

30 23. An apparatus for identifying which of a plurality of predetermined signal sequences is present in a received digital signal, comprising:  
means for comparing a selected portion of the received signal with two or more reference predetermined  
35 signal sequences;  
means for estimating the quality of the received signal; and

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means for selecting the identity of a predetermined signal sequence in the received signal on the basis of the comparison and the estimated signal quality.

5     24. The apparatus of claim 23, further comprising means for estimating the synchronisation position of the received signal on the basis of the comparison of a selected portion of the received signal with one or more predetermined reference signal sequences and an estimate  
10     of the quality of the received signal.

25. The apparatus of any one of claims 22, 23 and 24, wherein the comparing means comprises means for comparing the or each reference signal sequence with the  
15     selected received signal portion at each of a plurality of predetermined different time delays relative to the start of the selected received signal portion.

26. The apparatus of any one of claims 22, 23, 24 and  
20     25, wherein the comparing means comprises means for assessing the correlation of the or each reference signal sequence with the selected received signal portion at each of a plurality of predetermined different time delays relative to the start of the  
25     selected received signal portion.

27. An apparatus for synchronising a digital radio communications receiver to a received signal, comprising synchronisation means which uses the correlation of a  
30     selected portion of the received signal with one or more predetermined reference signal sequences and the estimated quality of the received signal to control the synchronisation of the receiver to the received signal.

35     28. An apparatus for identifying which of a plurality of predetermined signal sequences is present in a received digital signal, comprising means for using the

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correlation of a selected portion of the received signal with two or more predetermined reference signal sequences and the estimated quality of the received signal to identify the signal sequence.

5

29. The apparatus of any one of claims 22 to 28, wherein the signal quality estimating means comprises means for estimating the signal quality of only the selected portion of the received signal with which the reference signal sequence comparison is made.

10

30. The apparatus of any one of claims 22 to 29, comprising means for using the signal comparison results and signal quality estimates to define a decision function on which the synchronisation position estimation and/or the signal sequence identity selection is based.

15

31. The apparatus of claim 30, wherein the decision function defining means defines a decision function that includes either the product of the correlation value determined from the signal comparison and the corresponding signal quality estimate value, or the ratio of those values.

20

25

32. The apparatus of claim 30 or 31, comprising means for defining the decision function such that decision function always produces values falling within a fixed range regardless of the actual signal quality estimated and the signal comparison result.

30

33. The apparatus of claim 30, 31 or 32, comprising means for selecting the signal sequence identity and/or synchronisation position by searching over the set of time delays and the set of reference signal sequences to find which time delay and reference signal sequence combination gives the maximum value of the decision

35

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function.

34. An apparatus for estimating the synchronisation position of a received digital signal or for identifying  
5 which of a plurality of predetermined signal sequences is present in a received digital signal, comprising:

means for estimating a correlation value or values representative of the correlation of a selected portion of the received signal with one or more reference  
10 predetermined signal sequences;

means for estimating the received signal power; and

means for estimating the synchronisation position or signal sequence identity using the estimated correlation value divided by the signal power estimate.  
15

35. The apparatus of any one of claims 22 to 34, comprising means for rejecting the comparison step results, signal quality estimates, and/or the determined decision functions from the synchronisation position  
20 estimation or signal sequence identification, if they do not exceed a respective predetermined threshold value.

36. An apparatus for estimating the synchronisation position of a received digital signal, or for  
25 identifying which of a plurality of predetermined signal sequences is present in the received digital signal, comprising:

means for estimating the quality of the received signal; and

30 means for estimating the synchronisation position using the estimated signal quality or for identifying the signal sequence using the estimated signal quality.

37. A radio receiver for use in a digital radio  
35 communications system, comprising the apparatus of any one of claims 22 to 36.

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38. A computer program element comprising computer software code portions for performing the method of any one of claims 1 to 21 when said program element is run on a computer.

5

39. A method of estimating the synchronisation position of a received digital signal substantially as hereinbefore described with reference to any one of the accompanying drawings.

10

40. A method of identifying which of a plurality of predetermined signal sequences is present in a received digital signal substantially as hereinbefore described with reference to any one of the accompanying drawings.

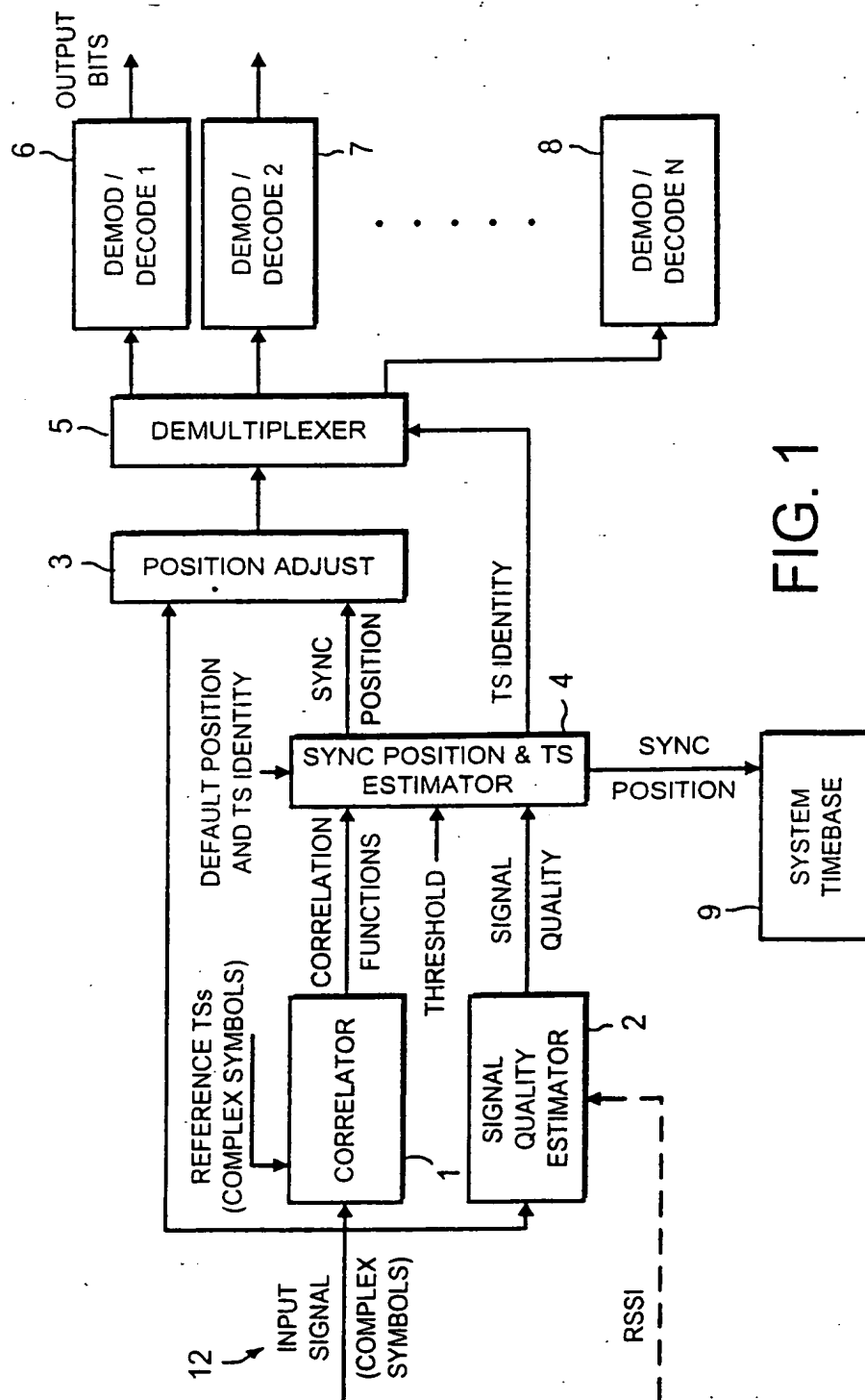
15

41. An apparatus for estimating the synchronisation position of a received digital signal substantially as hereinbefore described with reference to any one of the accompanying drawings.

20

42. An apparatus for identifying which of a plurality of predetermined signal sequences is present in a received digital signal substantially as hereinbefore described with reference to any one of the accompanying drawings.

25



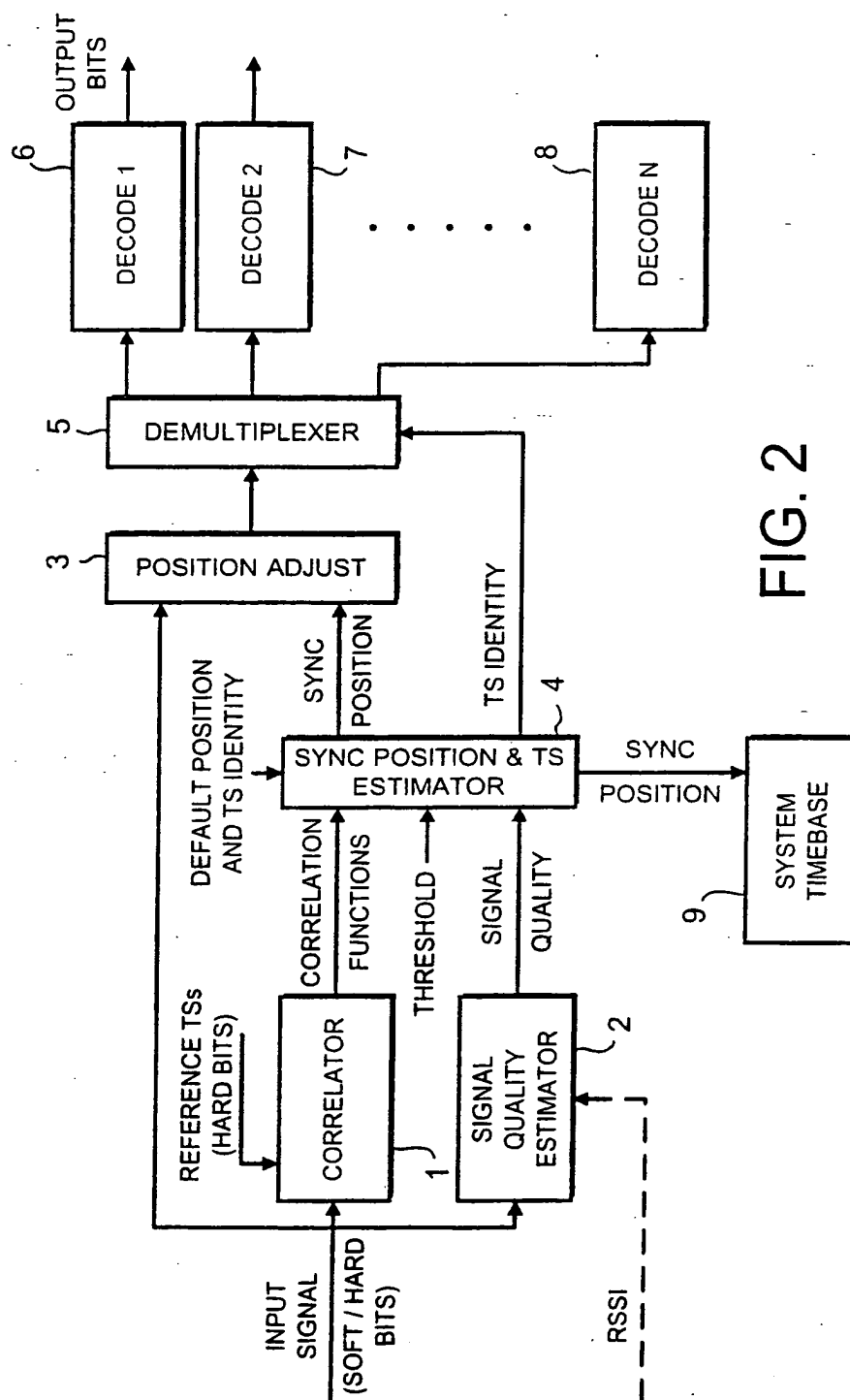


FIG. 2

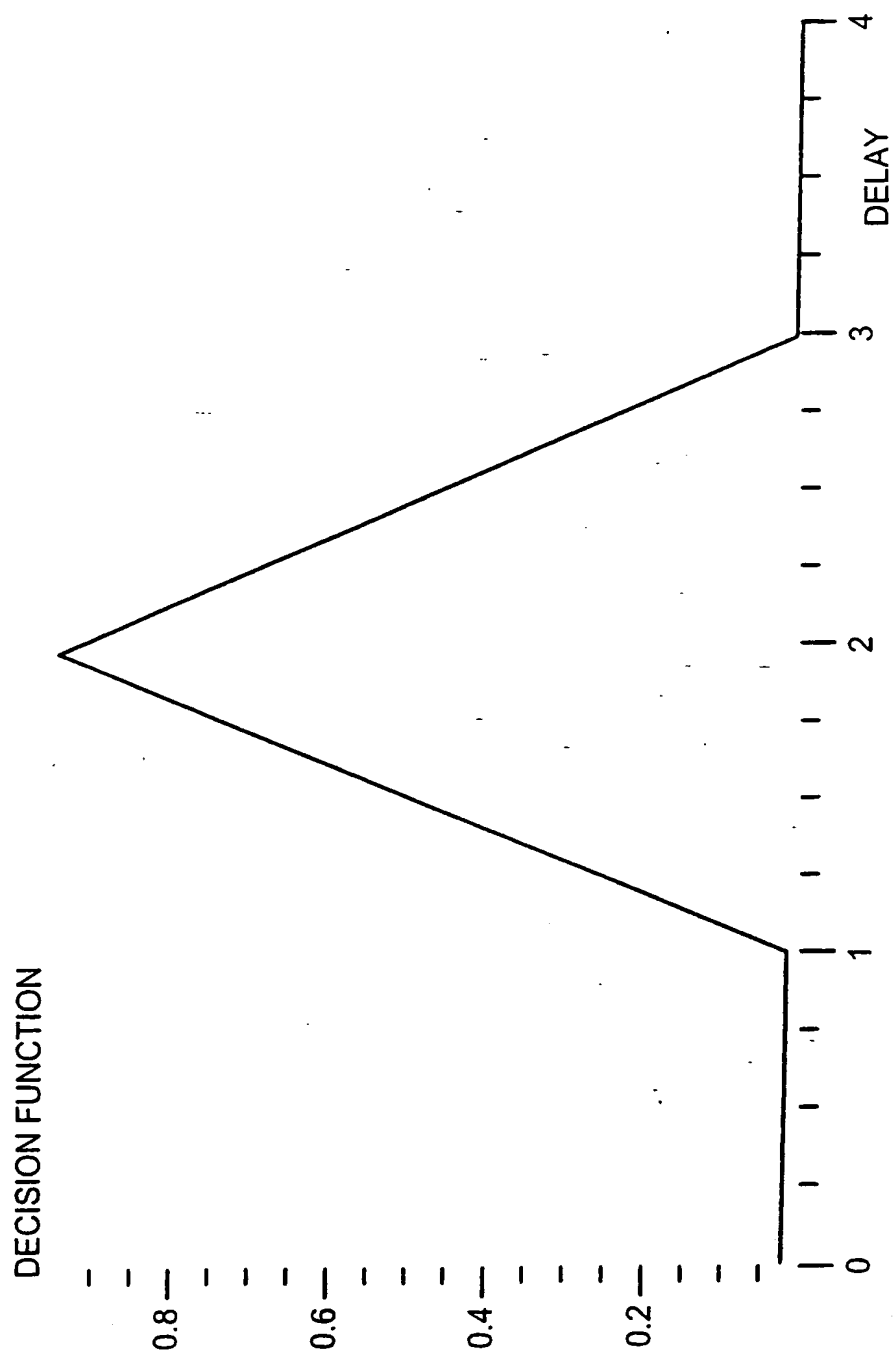


FIG. 3

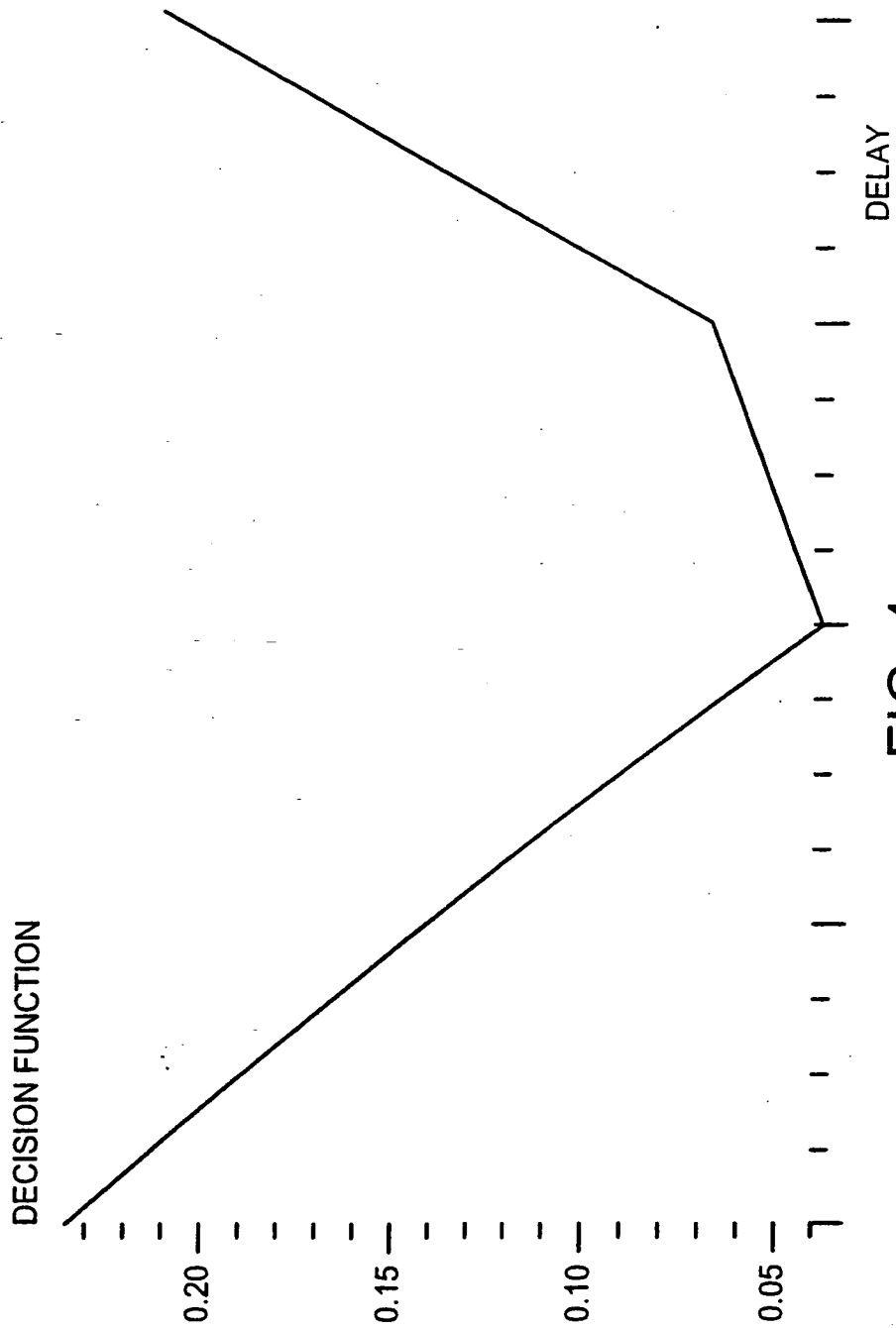


FIG. 4

# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/GB 99/04297

**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 7 H04L7/04

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FINA DE S: "SIMULTANEOUS FRAME AND BIT SYNCHRONIZATION OF HF RECEIVERS BY CONSTANT FALSE ALARM METHODS" EUROPEAN TRANSACTIONS ON TELECOMMUNICATIONS, IT, EUREL PUBLICATION, MILANO, vol. 7, no. 1, 1 January 1996 (1996-01-01), pages 83-91, XP000580351 ISSN: 1124-318X abstract parts 1 and 2	1-12, 20-29, 35-42
A		13, 17, 30, 34

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

\* Special categories of cited documents:

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
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- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

- \*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- \*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- \*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
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Date of the actual completion of the international search

12 May 2000

Date of mailing of the international search report

18/05/2000

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# INTERNATIONAL SEARCH REPORT

International Application No.

PCT/GB 99/04297

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 431 957 A (NIPPON ELECTRIC CO) 12 June 1991 (1991-06-12)  abstract page 3, line 12 - line 19	1-12, 20-29, 35-42
A	page 3, line 34 -page 4, line 19	13,17, 30,34
X	US 5 719 904 A (KIM JIN-GYU) 17 February 1998 (1998-02-17)  abstract	1-12, 20-29, 35-42
A	column 4, line 39 -column 6, line 9	13,17, 30,34
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A	page 1, line 4 - line 14 page 3, line 14 -page 7, line 2 page 8, line 9 - line 20 page 9, line 27 -page 10, line 34	13,17, 30,34
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A	column 10, line 42 -column 11, line 23	13,17, 30,34

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